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Subject: Balloon Project

Principal Investigator: Dr. Martin Schwarzschild

Executive Director: Dr. Robert E. Danielson

Period Covered: April 1963 - April 1964

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1. General Scheduling of Flights

As described in the preceding progress report, the first flight of Stratoscope II was carried out on March 1, 1963 with the result of obtaining the infrared spectrum of Mars. After this flight it became clear, that the various technical improvements shown necessary by the series of difficulties encountered during the first flight, as well as the transformation of Stratoscope II from its infrared configuration to its photographic configuration would require so much time that the first photographic flight could not be carried out before the second half of 1964. Such a long delay between flights would clearly have been most depressing for all involved. Furthermore, the first flight, though seriously handicapped by a number of technical difficulties, had we felt, clearly showed the great capability of Stratoscope II for astronomical research in the infrared, a field in which a substantial number of fundamental research problems exist, of which only one could be attacked in the first flight. Accordingly, it was decided to devote the second flight of Stratoscope II to infrared rather than photographic investigations, and the flight readiness date was scheduled for November 12, 1963.

Regarding plans for the period after the second flight, it appeared reasonable to assume that the transformation from the infrared to the photographic configuration could be carried out in one-year's time and accordingly the first photographic flight was scheduled for November, 1964.

Finally, with the scheduled gap of one year between the second and the third flight of Stratoscope II, it became possible to plan one more balloon test flight (Evaluation Flight No. 6), with a flight readiness date now scheduled for June [illegible] 1964. The aim of this test flight is to try out a couple of [illegible] would be of great benefit [illegible] for the first time on an actual [illegible].

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2. Balloon Developments

During the period before the second telescope flight the Vitro Laboratories put major efforts into further improvements of the balloon system and its operation. All the radio links were greatly strengthened including careful measurements of the relevant antenna patterns. After consultation with NCAR and other interested organizations, the wiring for all squibs was modified in such a way as to minimize the danger of premature firing by electrostatic charges collected on the balloon system. A major change was also made in the design of the sleeve which contains the lower two-thirds of the launch balloon during the early phases of the inflation. The aim of this change was to avoid any possibility of a repetition of the failure which occurred during the inflation attempt of February 22, 1963. This change proved itself eminently successful during the subsequent launching. Finally, with the help of the balloon theory group of A.D. Little, Vitro has developed a much improved ballasting policy and plan, with the effect of shortening the ascend time for the second Stratoscope flight wonderfully.

Since the second telescope flight the Stratoscope group in the Vitro Laboratory has concentrated on the preparation of the coming test flight. One of the two major aims of this test flight is to inflate the balloon system with 16,000 lbs. of helium lift rather than with 14,500 lbs. as was done up until now. The reason for trying this increased lift is the fact that the telescope weight has steadily been going up and will further go up in the photographic configuration. In consequence the ballast carried had steadily to be reduced since the total weight has to be kept constant as long as the lift cannot be increased. The reduction of the ballast carried is not serious if no complications arise during the whole flight. It does however decrease the flexibility of operations, particularly during the landing phases if complications are encountered. Detailed computations show that the increased lift of 16,000 lbs. in the present Stratoscope Balloon System should leave a safety factor of more than 2 even in the most critical phases during the ascent. These computations will be experimentally checked during the coming test flight by the photographic measurement of the launch balloon cone angle at the critical altitude of 12,000 ft.

The second aim of the test flight is to orient the dummy telescope during the landing phases in such a way that the side arm of the telescope is trailing with regard to the wind direction at landing. Such an orientation at contact with the ground would substantially increase the opportunity of small landing damage to the telescope. The instrumentation for this orientation has been developed and successfully tested in the laboratory. It consists of a compass which can be turned by radio command in accordance with the azimuth of the ground wind at landing time, and a fan which turns the telescope in accordance with the error signals received from the compass.

Finally major efforts have been made by the Vitro Laboratory to achieve a reduction in the price for the Stratoscope Balloon System. Gratifying progress has been made in this direction through the whole-hearted cooperation of the Schjeldahl Company.

3. Optical Work On Primary Mirror

The polishing of one of the two quartz mirrors of Stratoscope II (the one not used for the two infrared flights) has been completed. Thorough measurements with the scatter-plate technique have shown that the root mean square error of the figure of this mirror is now 1/50 of a visual wavelength and the maximum error is 1/20 wavelength. (Both these numbers having an uncertainty of about 10%.) Thus, it appears without any doubt that this mirror is the most accurate mirror of all mirrors of substantial aperture now in existence and fulfills the high requirements of photographic Stratoscope flights.

As it turned out the only stumbling block to achieving this high accuracy was the lack of a reliable method of measuring the figure of an optical surface to an accuracy of about one hundredth of a wavelength in the laboratory. When the scatter-plate method was finally developed by the Perkin-Elmer Corporation into a practical and reliable method the experts in that Company for optical polishing were found entirely capable to reduce the errors (precisely quantitatively determined from the scatter-plate photographs) with fine efficiency.

Less successful has been our attempt to measure the figure of this primary mirror at a cold temperature. Earlier tests had shown that the figure did not appear to change from room temperature to -40 centigrade. However these earlier results are not very accurate since in those tests we had not succeeded in obtaining sufficiently nearly isothermal conditions within the mirror. All subsequent attempts to obtain a more homogeneous temperature throughout the mirror blank during the cooling tests in the optical test chamber have failed. We now suspect that the strong temperature contrast between the warm walls of the test chamber and the cold coils surrounding the mirror within the chamber set up unexpectedly violent boundary flows of a complicated geometry which does not seem to be understood by the hydrodynamasists which we have consulted. Towards the end of 1963 it was decided to terminate, at least for the time being, the attempts of making accurate optical measurements at cold temperatures because of limitations in time and funds. The present lack of accurate optical measurements at cold temperatures would not appear too serious a worry in view of the homogenity of the quartz blank and the encouraging results of the earlier, less accurate, tests.

4. Repairs and Improvements of Telescope

The repair of Stratoscope II after its first flight cost approximately $200,000 which is about 8% of the total original cost of the instrument. As was expected, some of the outer relatively inexpensive structure of the instrument, such as the inertia wheel at the top and the truss around the side arm, needed substantial repairs and replacements. More unexpectedly, the "knuckle" which contains the delicate axis system was sufficiently damaged to require complete disassembly and replacement of all the flexure blades used in two of the three precision axes. Finally, substantial repair work was required for the electrical wiring of the instrument because of extensive damage by short circuits which occurred on the landing impact.

To reduce the landing damages just mentioned on future flights the following improvements were made. To protect the knuckle, automatic jacks were added. When at the end of the night of the flight the telescope is stowed in its latched position, these jacks go automatically in place in such a way that on landing they transmit the impact of the azimuth frame and the inertia wheel (heavily loaded with batteries) directly to the U-frame of the telescope which in turn carries the landing bumper at its bottom. Thus the landing impact of none of the heavy parts of the instrument is transmitted through the knuckle any more. To reduce the damage by short circuits the following development was carried out. Throughout the testing period all circuits are protected by fuses. During the final pre-flight procedure the fuses are made inactive by the insertion of multiple jumper plugs so that during the flight the operation cannot be aborted by the blowing of a fuse through an accident which otherwise might not be fatal. The new development has now added a devise which causes these fuse jumper plugs to be pulled out again by a barometric switch during the descent so that the fuses are active again and protect the electrical circuits against the effect of short-circuits on landing impact. Both these improvements proved most effective on the second flight.

Since guiding on the moon by hand from the ground station was found uncomfortably difficult during the first flight, an automatic moon guider was added, which made the telescope track the moon with ample stability and permitted during the flight, free choice of any lunar area to be projected on the spectrometer slit.

An important further area of improvement was the strengthening of all radio links, particularly, the telemetry channel, partly by increased transmitter power, and partly by larger and higher antennas. Furthermore, electronic filters were added which completely eliminated the interference between the radio command the the telemetry channels which had proved so bothersome during the first flight.

A major change was required in the television transmission link. Our temporary license for Channel 29 could not be extended in a more permanent way. On the advice of the FCC we applied for and obtained a new temporary license at 1500 m.c. This very high frequency assignment required a completely new transmission channel for the TV system. This channel was built by the RCA Laboratories at Princeton. It employed an 8 ft. parabolic receiving antenna and a parametric amplifier, and turned out reliable and effective.

Altogether, the strengthening of all the radio links makes it now probable that we have to cease operating the telescope during the flight only when the balloon at 80,000 ft. comes close to the line-of-sight horizon (2[illegible]0 miles) from the ground-station.

Finally, three major improvements were made in the infrared spectrograph. The germanium bolometers employed in the first flight were replaced by indium-arsenide detectors. The sensitivity of these detectors drops sharply beyond 3 microns; accordingly we could not have used them for the first flight because then a major aim was to obtain the spectrum of Mars out to 7 microns. However for the scientific aims of the second flight the limitation to 3 microns and below seemed not a serious restriction and the indium arsenide detectors have the great advantage that they work well down to about 0.9 microns while the germanium bolometers proved ineffective below about 1.7 microns. The new detectors with all their auxiliary electronic equipment were again produced and operated by Texas Instruments.

A second improvement in the infrared equipment was a modification of the magnetic tape recorder so that - in contrast to the first flight - it could operate securely in the ambient conditions during the flight.

The final improvement in the spectrograph was the introduction of an optical alignment mechanism for one of the mirrors inside the spectrograph which could be operated by command from the ground during the flight. Since the spectrograph contained a fairly large number of optical elements and since it is vitally essential that the light beam coming from the entrance slit of the spectrograph eventually ends well centered on the minute detectors in their nitrogen cooled dewar, the constancy of the internal spectrograph alignment had been a persistent worry and a likely loss of effective sensitivity. Now with the new device it was possible to move by command from the ground during the flight the one mirror slowly in the critical co-ordinate until maximum signal was received - thus assuring optimum spectrograph alignment.

5. Second Flight of Stratoscope II

The truck caravan carrying the disassembled instrument and all auxiliary equipment arrived at the NCAR Scientific Balloon Flight Center in Palestine, Texas on August 21, simultaneous with the entire Perkin-Elmer group and most of the Princeton group, headed by Dr. Danielson who planned and directed the entire instrument preparation operations as well as the ground station operations during the flight, in close cooperation with Mr. Alan Wissinger, the Perkin-Elmer Project engineer. (M. Schwarzschild arrived at Palestine one month later.) At the same date Dr. N. Woolf from Princeton and the spectrometer from Perkin-Elmer arrived at Texas Instruments in Dallas, Texas for the fitting of the new detectors and their electronic instrumentation into the spectrograph and the final testing and calibrating of this instrument. Four weeks later Dr. Woolf brought the spectrograph to Palestine where it was incorporated into the telescope. Early in November the Vitro group began their final preparations of the balloon system and the flight operations at Palestine.

The entire instrument reached flight readiness for November 25, only thirteen days later than the date planned more than six months earlier. The smallness of this schedule slippage was less caused by a lack of technical difficulties during the three months of instrument assembly and testing (though the amount of difficulties encountered this time was substantially less than during the preparation of the first Stratoscope II flight and were overcome in part particularly rapidly through the cooperation of Mr. Hemstreet from Perkin-Elmer and several of the RCA engineers who joined the regular group at Palestine on a couple of critical occasions), but rather more by the remarkably sustained working energy of all involved throughout the three months period, starting with an average working week of fifty hours and ending for many members of the group with a couple of weeks of over sixty hours.

The flight was cancelled for November 25, in view of the national day of mourning following the assassination of President Kennedy. On November 26 the carefully prepared meteorological predictions indicated favorable weather conditions and the flight was carried out. Thus in this case no postponement for weather reasons were encountered whatsoever.

Launch preparations by the Vitro group proceeded on schedule throughout the day and the launch, very smoothly, was executed at 4 p.m. The ascent was on the average somewhat faster than planned, presumably through a combination of the new ballasting schedule and a stratospheric temperature structure differing from the normal. The balloon reached its initial altitude of 85,000 ft. at 5:20 (after an average ascent rate of 1,000 ft. per minute) and sunset on the balloon followed at about 5:50. In consequence actual observations with the telescope could start at 6:00 p.m. All through the night the balloon descended slowly reaching an altitude of 70,000 ft. in the morning. This descent could not have been avoided by ballasting during the night. Since the descent rate however was so slow that it could not have noticeable disturbing effects on the astronomical observations it was decided not to interrupt the observations for ballasting operations.

On the day preceding the launch the ground station caravan moved to quarters near the site selected for the ground station location during the flight. On the launch day the ground station caravan reached the selected site, a slight rise with a free horizon all around and well away from likely electrical disturbances in the area of Ruston, Louisiana, at 12:00 p.m. By 3:45 the station was fully set up and the first telemetry contact with the balloon was made at 5:15 p.m. From then on the various internal electronic systems of the telescope were commanded on, one by one. At 5:30 p.m. a spectrometer scan on the on-board test scource was carried out and the unlatching operation, preparatory to actual observations was executed at 5:55, five minutes after sunset on the balloon. The balloon trajectory throughout the night was unusually favorable for the time of the year, so that the balloon stayed most of the night within a hundred miles of the ground station and never came anywhere close to the limiting range of any of the radio links, even at sunrise the next morning. Accordingly, observations could be carried out throughout the night until 5:45 a.m. when the relatching operations had to be started. Sunrise on the balloon occurred at 6:11 and the latching was completed at 6:16 a.m. Thus a full twelve hour night had been available for astronomical observations.

During these twelve hours all the instrumentation, both at the telescope and in the ground station, operated without any major troubles. This fact appears a bit of a miracle, even in afterthought. Stratoscope II, contrary to our original hopes, has grown - by necessity we feel - into a quite complicated instrument as is shown, for example, by the fact that it contains approximately 40 motors run by command from the ground, 4 stepper switches, each of twenty-four or more positions, and 2 image orthicon cameras never, it seems, employed in any other space program this far. It appears under these circumstances reasonable to expect that Stratoscope II should on the average operate on a flight with satisfactory scientific effectiveness. However it seems not possible to avoid the conclusion that the extraordinary effectiveness of this particular flight was in part caused by sheer luck.

During the twelve hour observing period spectrometer scans were obtained of ten astronomical objects: Jupiter, Moon, Aldebaran, Mu Cephei, Betelgeuse, Mira, Sirius, R Leonis, Rho Persei, Mu Geminorum. The time spent on the various types of operations throughout the night can be seen by the following tabulation:

Acquisition of objects and adjusting of instrument:	250 minutes,
Spectrograph alignments:	20 minutes,
Trouble shooting:	50 minutes,
Scanning of on-board source:	30 minutes,
Scanning of stellar spectra:	370 minutes.

Accordingly, even if one considers solely the scanning of stellar spectra as "useful" time, just over 50% of the total twelve hours were usefully employed.

The eleven member ground station crew, by a careful distribution of duties, could just about manage to maintain the necessary energy throughout the very long and active night. Also the decisions made after the first flight regarding changes in the items to be handled by automatic instrument operations or by human decisions from the ground seemed to work out effectively; specifically it was a great relief to the ground crew to have an automatic moonguider, not available in the first flight, while on the other hand it was no appreciable trouble to the ground station crew to operate by command the spectrograph alignment which substantially increased the effective sensitivity.

The effect of the judgement of the scientists in the ground station became strikingly evident as the night progressed. The spectrometer tracings transmitted by the telemetry channel, though not quite so good as those recorded on magnetic tape up at the telescope, clearly showed the essential new features observed, and the observing program for the later parts of the night was substantially affected by the findings of the earlier hours. An instrument less commandable from the ground and more pre-programmed, would not have permitted this flexibility nor the consequent increase of scientific effectiveness of the flight.

In the morning after the instrument had been relatched the control over the balloon was returned to the Vitro group which had carefully tracked the balloon all through the night from planes and ground vehicles. To initiate the descent, valving started at 6:30 a.m. and repeated at appropriate intervals until 8:10 a.m. The balloon passed through the tropopause soon thereafter with a speed of about 400 ft. per minute, very close to the planned value. As expected, it then speeded up its descent to nearly a 1,000 ft. per minute which was held in check and eventually slowed down by appropriate ballasting. Since unexpectedly the landing area was covered by low clouds, the final landing was carried out without visual contact in an area of very low population density with full control of the landing speed through ballasting commands and descent speed telemetry. The actual impact velocity was 500 ft. per minute, 20% less than the planned value.

The landing occurred near Kosiusko, Mississippi, in a woods about one-half a miles from the nearest road. It is not clear whether the trees among which the telescope landed increased or decreased the landing damage. In any case, the landing damage turned out even smaller than after the first flight amounting to about $150,000 of repair cost. No difficulties were encountered in having an access road bulldozed to the landing site. However heavy rain on November 28 somewhat slowed down the recovery operation which nevertheless was completed on November 29. Two days later the telescope was back on its way to the Perkin-Elmer Plant in Connecticut.

In the meantime on November 28, the ground station returned to Palestine. The tape recording containing all the scientific results of the flight was flown from the landing site to Palestine on November 29, and the transfer of the data from the magnetic tape to graphical records used for the subsequent reductions was accomplished by December 2.

6. Scientific Results From Second Flight

During the five months elapsed since the flight the spectrometer tracings have been read off point by point, punched onto cards, reduced by an electronic computer for instrument sensitivity and wavelength calibration and the several tracings for each of the ten objects and each of the two detectors have been averaged. From the final curves which give the intensity distribution of the light of each of the ten objects in the wavelength range from 0.90 to 3.05 microns the following six points can be deduced.

1. The spectra of the Moon, Aldebaran, and Sirius show that the terrestrial atmosphere above the balloon (80,000 ft.) had no disturbing effects on the measurements; the only terrestrial band weakly indicated in the spectra is that of carbon dioxide at 2.7 microns.

2. The spectrum of the Moon shows an increasing albedo from 1 to 1.7 microns, a flattening of the albedo between 1.7 and 2 microns and finally, an increase in the intensity above 2.0 microns in accordance with the expected thermal emission of the Moon.

3. The spectrum of Jupiter shows deep methane bands at 0.85, 0.99, 1.14, 1.37, and 1.7 microns and the ammonia fundamental band at 3.0 microns. A very broad feature in Jupiter's spectrum from 2.0 to 2.5 microns is probably caused by combination bands of methane with the possibility of a contribution from the hydrogen molecule.

4. The spectrum of Aldebaran (K5) shows practically no bands but has a clear intensity peak around 1.6 microns where the bound-free and the free-free absorption of H^- and H_2^- leave a relatively transparent region in the continuous absorption coefficient; the same phenomenon is also shown by the spectra of the cooler giants though complicated by band structure.

5. Betelgeuse (M2) clearly shows the water vapor bands at 1.4 and 1.9 microns as well as indications of a band at 2.7 microns; also the carbon monoxide band at 2.3 microns is fairly strong. The spectra of R Leonis (M8) and particularly of Mira at minimum (M9) show the water vapor bands at 1.4 and 1.9 microns with extreme strength. These results appear of substantial consequences for the theory of cool stellar atmospheres.

6. Finally, the spectrum of Mu Cephei permits the determination of an upper limit for the absorption of interstellar ice grains in the band at 3.1 microns; this upper limit turns out rather smaller than the expected value.

It is planned that these results will be published in the Astrophysical Journal in four papers; one on the Moon, one on Jupiter, one on the Red Giants, and one on Interstellar Ice Grains. However, the writing of these papers has only just been started. The summary of these results will be presented during the meetings of the American Astronomical Society at Flagstaff late in June.

7. Preparations For First Photographic Flight

Since the last flight the Perkin-Elmer Corporation has completed the repairs of the telescope for the landing damage; as mentioned earlier, these damages were relatively light, in part because of the protective improvements incorporated since the first flight.

One of the instrumental problems irrelevant for the infrared flights and vital for the photographic flights is the alignment of the Gregorian Secondary Mirror relative to the Primary Mirror. Accordingly, very precise flexure tests have recently been carried out with the telescope structure. It was found that this structure is just about rigid enough when moved through the entire range of elevation desirable for observations, but that it is not sufficiently invariable (though missing the requirements only by a moderate factor) over the necessary temperature range, as shown by relative tests made at room temperature and at a cold New England winter night temperature. In consequence the decision was made to terminate the flexure tests and not to try to improve the characteristics of the structure, but instead to accept the concept of in-flight alignment which had proven so successful on the smaller scale of the spectrograph during the last flight. Accordingly, ground commanded motors have been installed which can move the secondary mirror in two coordinates over small ranges (the third coordinate being covered by the focusing motion which the instrument of course always has had). In addition a photoelectric sensor is being added which scans the diffraction image of a bright star with a slit, first in one coordinate and then in the other coordinate with the resulting data being telemetered to the ground. Thus it will be possible to observe in the ground station any coma caused by malalignment and then to correct the alignment by appropriate commands. This operation will obviously take some time during the flight; but it appeared the only safe solution for overcoming the flexure problem. Besides this appeared attractive as it represents a pilot undertaking for a type of operation which nearly certainly eventually has to be employed in high definition satellite experiments.

The second problem area which now has to be solved in preparation for the first photographic flight is that of the pre-launch cooling of the Primary Mirror. The difficulties to be overcome in this area are first; inhomogeneity in the cooling which would lead to possible slight distortions in the perfect mirror figure, and second, the avoidance of even the slightest condensation of water on the Primary since this would likely not evaporate throughout the whole flight. The final cooling tests are now underway at the Perkin-Elmer Plant and have gone very well this far though they are not yet completed.

The third new preparation area is the combination of the coarse pointing servo system (which has worked successfully in the two infrared flights) with the internal fine guidance servo-system (which has been successfully tested by itself in the laboratory, but has not flown yet). Since the testing of the combined system requires the fully assembled telescope it is planned that these tests will be carried out only after the instrument is shipped again to Palestine (now scheduled for June 17) and there re-assembled in the Stratoport.

8. Integrating Television

To fully exploit the high potential resolution of Stratoscope II a very long effective focal length has to be used; otherwise the resolution may be lost in the graininess of the receiver, be that a photographic emulsion (as will be the case in the first photographic flights) or an image tube (as may hopefully be employed in the later flights). Accordingly, Stratoscope II has been designed with an effective focal length of 300 ft. which gives it a focal ratio of 1:100, making it an extremely slow camera indeed. Thus the highest possible sensitivity of the receiving surface is of unusual importance for Stratoscope II. Because of this circumstance this project is vitally interested in the use of image tubes employing photocathodes which have a basic quantum efficiency about 30 times higher than the best photographic plates.

With this in mind a Development Contract has been given to Dr. Zworykin's group at the RCA Laboratories in Princeton to study the use of an image-orthicon tube as an integrating receiver in place of the photographic emulsion. This contract was completed late in 1963 with most encouraging results.

A commercially available image-orthicon, though not one of the most standard ones, was employed for the test. The operation of this tube, as finally developed for the eventual application in Stratoscope II, differs however greatly from the standard operation. The three basic actions, exposing, reading, and wiping, which in the standard operation are effectively done continuously and simultaneously, are in the new operation entirely separated in time. Thus conditions can be optimized for each of the three actions separately. Specifically, during the integrating exposure time which in the tests has been stretched to as long as two hours, the reading beam is completely turned off. Similarly, when after the exposure the reading beam is turned on, it is adjusted so that to be optimum for the reading operation alone, particularly with regard to the faintest parts of the exposed image, but without any regard to the completeness to the wiping of the image which is handled in a separate action afterwards.

The final tests carried out at the RCA Laboratories strongly suggest that a factor of 10, if not as high as 30 over the best available plates, can be achieved with this tube and this type of operation. This most encouraging result regarding the sensitivity must not be taken however as indicating that such an image-orthicon application is the cure-all for all astronomical image taking research; particularly the problems regarding accurate photometric measurements within the image have not yet been studied in these tests.

On the basis of the very positive results of the first contract, a second contract has recently been given to the RCA Laboratory to build a "flying breadboard version" of this type of integrating TV camera, designed in such a manner that it first can be employed with a ground based telescope, largely for practicing purposes, and then, if successful, can be incorporated in Stratoscope II for later flights.